Gauge Coupling Unification in Heterotic String Models with Gauge Mediated SUSY Breaking

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Work with Prof. Stuart Raby

Archana Anandakrishnan

The Ohio State University

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Motivation

In string theories with compactified extra-dimensions, there generically exist extra non-standard model particles, usually called “exotics”.

To mediate SUSY breaking with vector-like “exotic” particles arising from heterotic string theory, and produce a “consistent” low-energy spectrum.

Mini-Landscape Search[1]

- Search for MSSM spectrum at low energies starting with $E_8 \times E_8$ heterotic string models compactified on the orbifold, $T^6/\mathbb{Z}_6$
- Look for GUTS with the Standard Model Gauge group embedded

$$E_8 \supset E_6 \supset SO(10) \supset SU(5) \supset G_{SM}$$

- Spectrum: Three families + Vector-like "exotics"
- 15 models with promising phenomenology.

[1] O. Lebedev, H. P. Nilles, S. Raby, S. Ramos-Sanchez, M. Ratz, P. K. S. Vaudrevange and A. Wingerter, Phys. Lett. B 645, 88 (2007)

Gauge Coupling Unification

• Gauge Coupling Unification was studied in 2 of these 15 models in the current work and earlier[2].

Model 1 and Model 2A

• This required some of the vector-like exotics to be massive at less than 10^{15} GeV.
• Solutions were constrained by the value of proton lifetime in these models.

$$\tau(p \to \pi^0 e^+) \gtrsim 10^{34} \text{ yr}^*$$

* Current bound from Super Kamiokande.

[2] Ben Dundee, Stuart Raby, Akin Wingerter - Phys.Rev.D78:066006,2008

Matter Content and Energy scales

- $\vec{n} = (n_3, n_2, (n_1, n_1'))$ defines the 'light' exotic matter content of the theory.

$$n_3 \times \left[(3,1)_{1/3} + (\overline{3},1)_{-1/3}\right] + n_2 \times [(1,2)_0 + (1,2)_0] + n_1 \times [(1,1)_1 + (1,1)_{-1}]$$

- M_{EX1}- Mass scale of the triplet exotics.
- M_{EX2} - Mass scale of the doublet exotics.
- M_C - The compactification scale of the extra-dimensions.

The singlets are allowed to be massive either at M_{EX1} or M_{EX2}.

Heterotic Theory on Orbifold

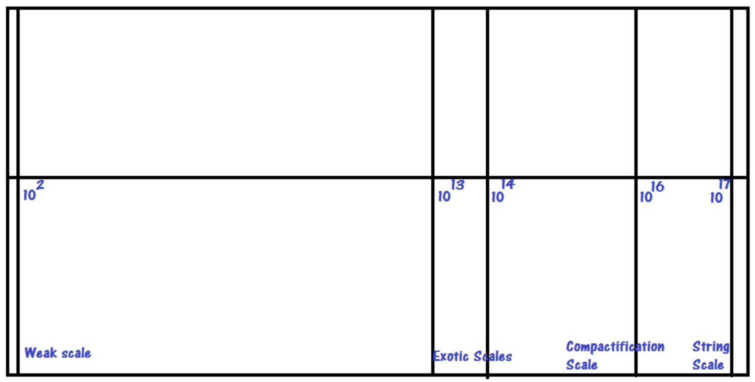
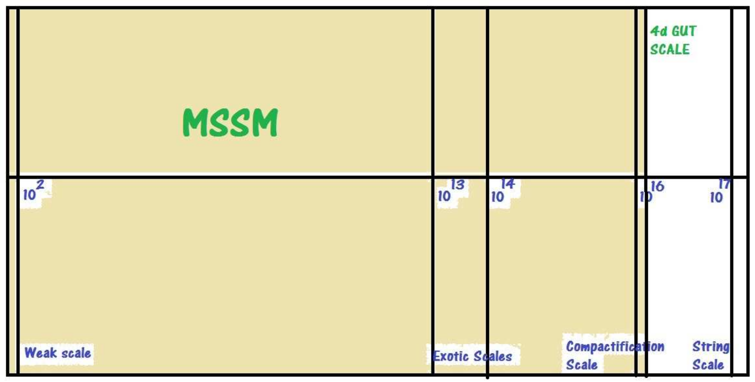


*Figure not drawn to scale.

4D MSSM



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4D MSSM

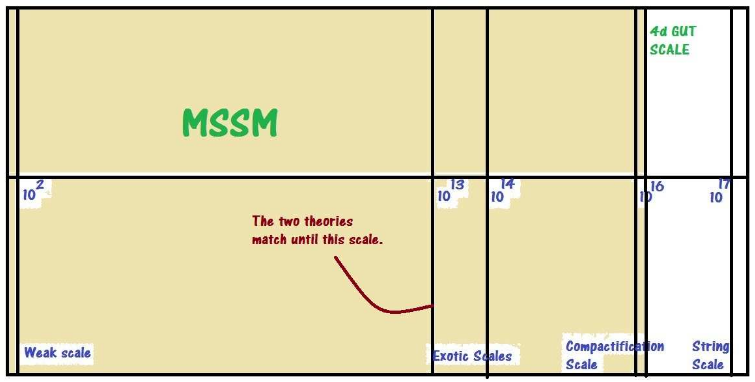
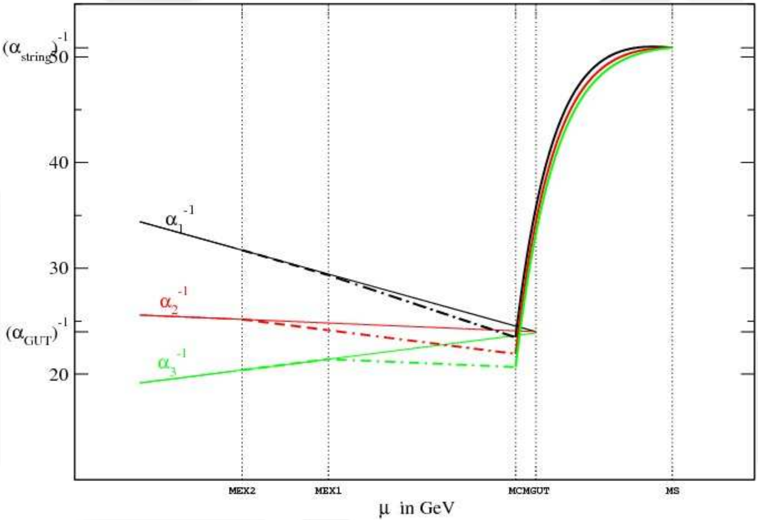


*Figure not drawn to scale.

Gauge Coupling Unification



Gaugino Masses

- The gauginos obtain mass at one loop from the exotics:

$$M_i = b_i^{EX3} \frac{\alpha_i}{4\pi} \frac{F^\phi}{M_{EX1}} + b_i^{EX2} \frac{\alpha_i}{4\pi} \frac{F^\phi}{M_{EX2}}$$

The two exotic scales give rise to non-universal gaugino masses.
The gravitino contribution is sub-dominant when:

$$\frac{F^\phi}{M_{EX}} >> m_{3/2}^*$$

$$b^{EX3} = (n_3, 0, \frac{n_3 + 3n_1}{10}) \qquad b^{EX2} = (0, n_2, \frac{3n_1'}{10})$$

* Anomaly contributions to gaugino masses were considered in a recent analysis.

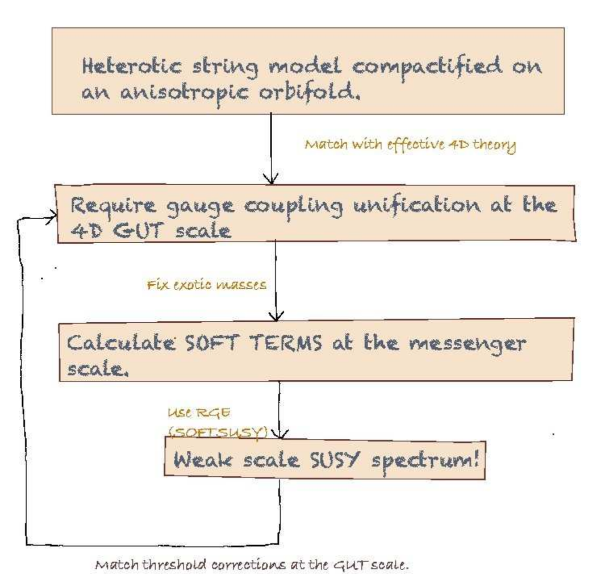
Scalar Masses

- The scalars obtain mass at two-loops:

$$m_{\phi_i}^2 = m_{3/2}^2 + 2\left(b_3^{EX3}\,\frac{\alpha_3}{4\pi}\,\frac{F^\phi}{M_{EX1}}\right)^2 C_3(i) + 2\left(b_2^{EX2}\,\frac{\alpha_2}{4\pi}\,\frac{F^\phi}{M_{EX2}}\right)^2 C_2(i)$$
$$+2\left(\frac{\alpha_1}{4\pi}\left(b_1^{EX3}\,\frac{F^\phi}{M_{EX1}} + b_1^{EX2}\,\frac{F^\phi}{M_{EX2}}\right)\right)^2 C_1(i) + dQ_a^X M_2^2$$

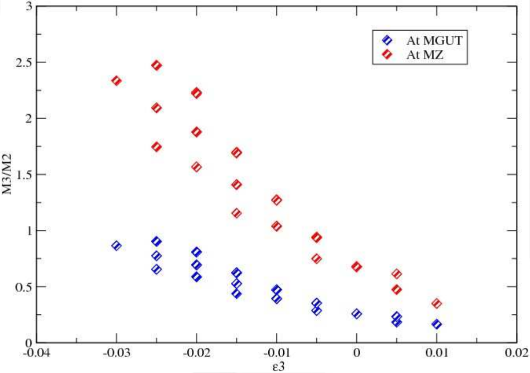
- $dQ_a^X M_2^2$ is a possible D - term contribution from an anomalous $U(1)_X$ that is proportional to GMSB.
- The large gravity contribution makes the scalar masses universal at the GUT scale.

The road to MSSM



Effect of ϵ_3

- We study the effect of threshold corrections on the spectrum of exotics as well as the low energy spectrum.



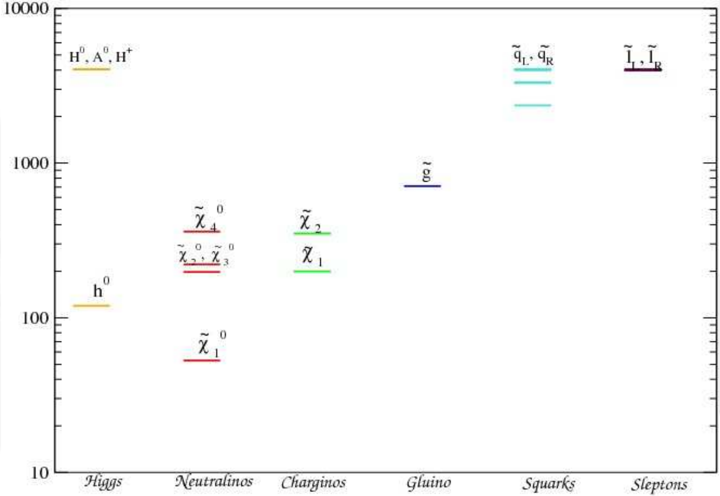
The figure represents the correlation for one particular model with $\vec{n} = (4, 2, (2, 1))$

Two Cases

Observable	Case 1	Case 2
$m_{3/2}$	4 TeV	10 TeV
d	0	5
M_S	6.04×10^{17}	6.05×10^{17}
M_C	1.2×10^{16}	1.2×10^{16}
M_{EX1}	5.03×10^{13}	1.10×10^{14}
M_{EX2}	1.69×10^{13}	8.54×10^{13}
M_{GUT}	2.5×10^{16}	2.0×10^{16}
ϵ_3	-2.5 %	0 %
$\tan\beta$	7	4
mu	-206.217	-1932.930

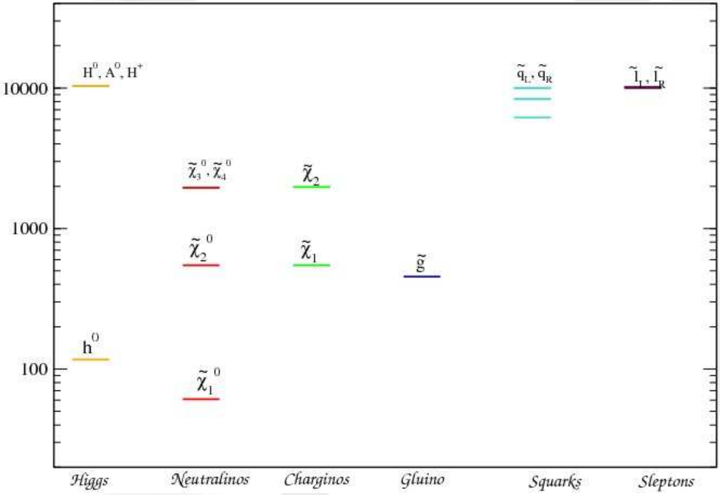
MSSM Spectrum - Case 1

$m_{3/2} = 4$ TeV, d = 0, $\epsilon_3 = -2.5$ %



MSSM Spectrum - Case 2

$m_{3/2} = 10$ TeV, d = 5, $\epsilon_3 = 0$ %



Implications of latest results from LHC

- The main difference between the spectrum discussed here and CMSSM is the non-universality of gaugino masses.
- Kinematically, the signatures from this spectrum would be similar to CMSSM with heavy scalars.
- Results presented at EPS 2011 from ATLAS: Gluino masses of 200 GeV - 660 GeV ruled out for neutralino masses up to 160 GeV.
- These results heavily constrain the parameter space discussed here.

Summary

• We have a self-consistent spectrum generated from heterotic string theory with vector-like "exotic" particles mediating SUSY breaking.

• The threshold corrections at the GUT scale depend on the gaugino masses.

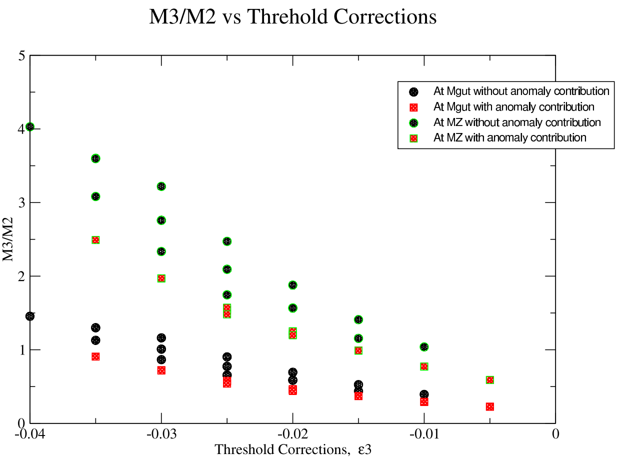
• A large region of the parameter space discussed here is ruled out by the latest results from LHC.

EXTRA SLIDES

Exotic Spectrum

Model	Hidden Sector		Exotic Matter Irrep	Name
1 A/B	$SU(4) \times SU(2)$	brane exotics	$2 \times \left[(3,1;1,1)_{1/3,2/3} + (\bar{3},1;1,1)_{-1/3,-2/3}\right]$	$v + \bar{v}$
			$4 \times \left[(1,2;1,1)_{0,*} + (1,2;1,1)_{0,*}\right]$	$m + m$
			$1 \times \left[(1,2;1,2)_{0,0} + (1,2;1,2)_{0,0}\right]$	$y + y$
			$2 \times \left[(1,1;4,1)_{1,1} + (1,1;\bar{4},1)_{-1,-1}\right]$	$f^+ + \bar{f}^-$
			$14 \times \left[(1,1;1,1)_{1,*} + (1,1;1,1)_{-1,*}\right]$	$s^+ + s^-$
		bulk exotics	$6 \times \left[(3,1;1,1)_{-2/3,-2/3} + (\bar{3},1;1,1)_{2/3,2/3}\right]$	$\delta + \bar{\delta}$
			$1 \times \left[(3,1;1,1)_{-2/3,-1/3} + (\bar{3},1;1,1)_{2/3,1/3}\right]$	$d + \bar{d}$
			$1 \times \left[(1,2;1,1)_{-1,-1} + (1,2;1,1)_{1,1}\right]$	$\ell + \bar{\ell}$
2	$SO(8) \times SU(2)$	brane exotics	$4 \times \left[(3,1;1,1)_{1/3,*} + (\bar{3},1;1,1)_{-1/3,*}\right]$	$v + \bar{v}$
			$2 \times \left[(1,2;1,1)_{0,*} + (1,2;1,1)_{0,*}\right]$	$m + m$
			$1 \times \left[(1,2;1,2)_{0,0} + (1,2;1,2)_{0,0}\right]$	$y + y$
			$2 \times \left[(1,1;1,2)_{1,1} + (1,1;1,2)_{-1,-1}\right]$	$x^+ + x^-$
			$20 \times \left[(1,1;1,1)_{1,*} + (1,1;1,1)_{-1,*}\right]$	$s^+ + s^-$
		bulk exotics	$3 \times \left[(3,1;1,1)_{-2/3-2/3} + (\bar{3},1;1,1)_{2/3,2/3}\right]$	$\delta + \bar{\delta}$
			$1 \times \left[(3,1;1,1)_{-2/3,2/3} + (\bar{3},1;1,1)_{2/3,-2/3}\right]$	$d + \bar{d}$
			$1 \times \left[(1,2;1,1)_{-1,-1} + (1,2;1,1)_{1,1}\right]$	$\ell + \bar{\ell}$
			$3 \times \left[(1,2;1,1)_{-1,0} + (1,2;1,1)_{1,0}\right]$	$\phi + \bar{\phi}$

Anomaly Contributions



$m_{\tilde{\chi}^0}$ vs $m_{\tilde{g}}$